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DISSOLVED ARSENIC TREATMENT FOR THE DEWATERING AND OPERATION OF THE OLD AUGMITTO GOLD MINE, ROUYN NORANDA, QUEBEC, CANADA

Bernard Aubé P.Eng, M.A.Sc.
Water Treatment Expert, EnvirAubé, Ste-Anne-de-Bellevue, Québec, Canada, aube@enviraube.com

Louis Bernier, PhD
Vice President Exploration and Chief Operating Officer, Yorbeau Resources Inc., Montréal, Québec, H2P 1B9, lrbernier@yorbeauresources.com

Abstract: The old Augmitto gold mine is located along the Cadillac-Larder Lake fault zone and was developed in the 1980's. The Augmitto mine never went into production due to the bankruptcy of a previous owner in 1988. The mine comprises a 1.5 km ramp with 11 levels of underground development at a maximum vertical depth of 185 meters. The property is now owned by Yorbeau Resources Inc. and the Augmitto mine is currently the object of a partial dewatering to test the water treatment installation and evaluate the quality of the underground infrastructure. A total of 90,000 m^3 of water will have to be pumped out during the dewatering of the mine, which is currently under evaluation. The permitting received for the dewatering of the Augmitto ramp will allow Yorbeau Resources to extract a bulk sample of up to 100,000 tonnes and to undertake an underground exploration program if a go decision is given. Pumping at an estimated rate of 200 m^3/day will be necessary to maintain the mine dry during operation. The underground mine overflow water was regularly monitored in the past year (2006-2007) and was shown to contain up to 0.40 mg/L of arsenic (As). Samples taken deep in the mine workings showed values of up to 0.94 mg/L. The regulated limit for discharge to the environment in Québec, Canada is 0.20 mg/L of As as a monthly average. Laboratory tests were completed to evaluate the requirements for treatment of these low concentrations of As. These tests were based on the use of ferric sulphate addition to co-precipitate the As with the resulting ferric oxy-hydroxides. Tests completed at different Fe:As ratios and different pH setpoints, with and without oxidants, showed that ferric sulphate addition alone could efficiently remove the As from solution. Based on the laboratory results, existing settling ponds were enlarged and a reactor was constructed to treat the mine water. Full-scale operating trials showed that the As removal from solution and particle settling in the ponds was very efficient with final As concentrations of less than 0.1 mg/L. In this paper, the source of As is reported, the laboratory tests are described, and the full scale process and treatment results are detailed.

INTRODUCTION

The old Augmitto gold mine is part of the Rouyn property which lies 7.3 km southwest of the city of Rouyn-Noranda, Quebec and is located in Canada's well-known Abitibi Greenstone Belt (Figure 1). Since the early 1900s, this greenstone belt has produced nearly 200 million ounces of gold from world-class mines such as the McIntyre, Kerr-Addison, Sigma-Lamaque, Lakeshore (8 million ounces) and numerous others.

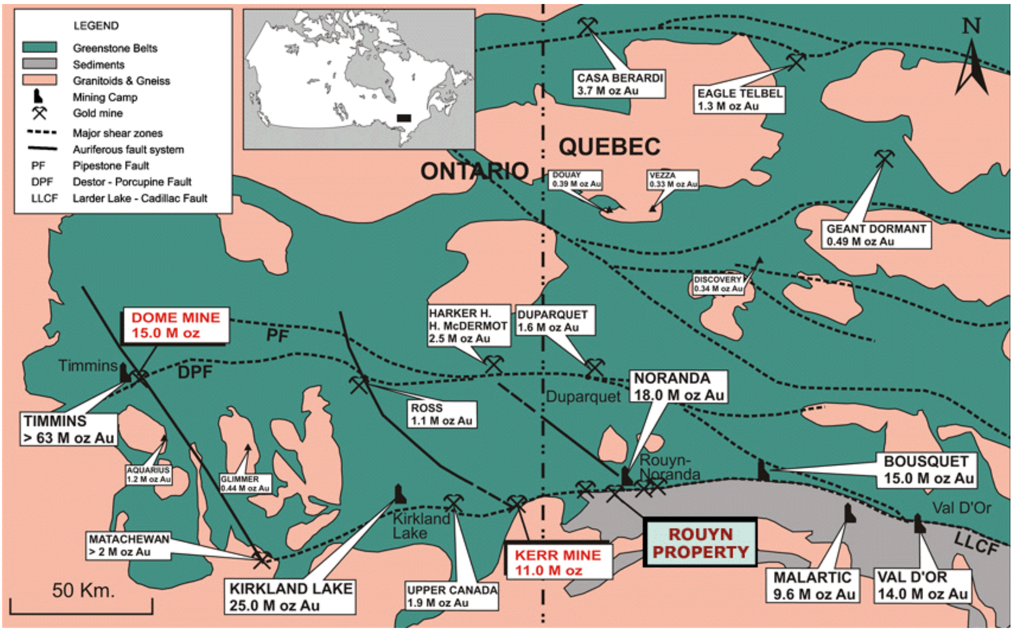

Figure 1: Rouyn Property (Augmitto and Astoria mines) Location Map

The Augmitto mine never went into production due to the bankruptcy of a previous owner (Augmitto Exploration Ltd) in 1988. The mine comprises a 1.5 km ramp with 11 levels of underground development at a maximum vertical depth of 185 meters. The Rouyn property is currently the object of extensive surface definition and exploration drilling. A partial dewatering of the old Augmitto ramp was conducted on August 6 until September 27th 2007 to: 1) commission the newly designed water treatment plant, 2) test the new water ponds, and 3) evaluate the quality of the underground infrastructure. The dewatering of the Augmitto ramp will allow Yorbeau Resources to extract a bulk sample of up to 100,000 tonnes and to undertake an underground exploration program.

This paper present the results of the laboratory testing that led to the design of a water treatment plant with a capacity to treat up to 3,000 m^3/day at a maximum arsenic concentration of 2 mg/L. This is more than twice the maximum arsenic concentration analysed in the sampled mine water. The water quality monitoring results during the plant operation are also reported.

GEOLOGICAL SETTING AND GOLD MINERALIZATION

The Rouyn Property host two gold deposits (Augmitto and Astoria) and covers a 12-kilometre stretch of the Cadillac-Larder Lake Tectonic Zone (CLLTZ) (Gauthier et al., 1990). It is 100% owned by Yorbeau Resources Inc. It consists of two mining leases, one mining concession and 81 claims, and covers a total area of nearly 2,700 hectares.

Gold occurs primarily in two types of mineralization that were also characteristic of the Kerr-Addison deposit which produced about 11 million ounces of gold during its 58-year production life: carbonate ore and so-called 'flow' ore (principally observed at the old Astoria mine, 5 km east of the Augmitto deposit). The carbonate ore typically contains free gold in quartz veins stockworks associated with carbonate alteration zones in komatiitic flows (Cloutier, 1999). The previous owner completed extensive underground development and the delineation of pre-NI-43-101 historical reserves on the Augmitto deposit (ACA Howe 1988). The Astoria deposit contains NI-43-101 undiluted total reserves of 2.74 M tonnes grading 3.96 g/t and 0.4 M tonnes inferred resources at 4.74 g/t (Puritch, 2005).

Arsenic mineralogy

Arsenic is dominantly hosted in arsenopyrite (FeAsS) and in the accessory mineral gersdorfite ((Ni,Co,Fe)AsS). Arsenopyrite is observed as large euhedral crystals showing prismatic and lozenge sections frequently in association with brown tourmaline and carbonates at the margin of quartz veins stockworks (Figure 2). Gersdorfite is disseminated in the sheared matrix of the green carbonate ore and is observed in very small grains associated with sericite and fuchsite (Figure 2). The green carbonate ore has net neutralization potential (NNP) values ranging between 132 and 292 kg $CaCO_3$/t indicating it is not potentially acid generating (Bernier, 2006). The whole rock chemistry indicates a wide range of arsenic concentration in the komatiite and green carbonate ore varying from 2 ppm up to 16,000 ppm in ore, with an average of 510 ± 1,121 ppm. Thus water circulating through these carbonatized ultramafic rocks will generate slightly alkaline drainage and arsenic leaching and mobilisation upon oxidation of the As-bearing minerals (Shaw, 2006).

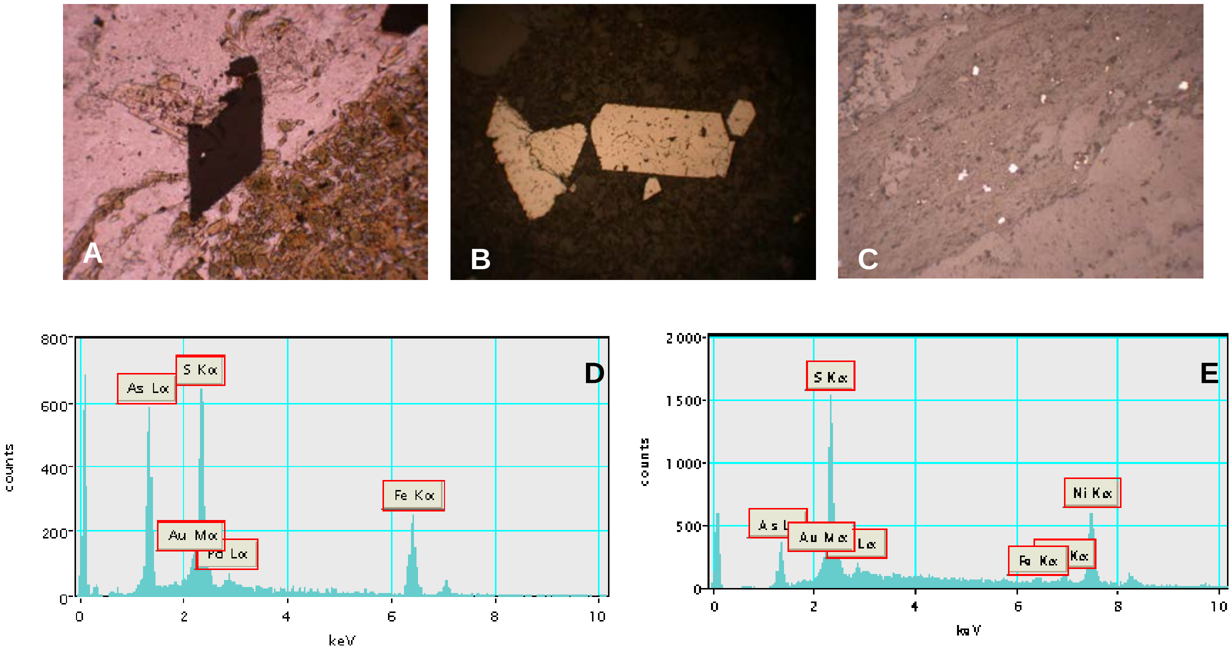

Figure 2: A Photomicroscope of Arsenopyrite (Black Lozenge) Near Brown Tourmaline in a Quartz Carbonate Veinlet, Polarized Light 40X; B) Photomicroscope Of Arsenopyrite Crystals in Reflected Light, 40X; C) Gersdorfite Grains in Fuchsite Zone, Green Carbonate Ore, Reflected Light, 40X; D) EDS Spectra of Arsenopyrite; E) EDS Spectra of Gersdorfite; Au Peaks Are From Gold Coating on Polished Thin Section

ARSENIC TREATMENT THEORY

There are many different technologies in use for treatment of dissolved arsenic (As) either for potable water or for environmental release. These treatment types include precipitation/co-precipitation, membrane technologies such as reverse osmosis, adsorption treatment, ion exchange, and permeable reactive barriers (US EPA, 2002). The most widely used, co-precipitation of As, is discussed in this paper.

Treatment of arsenic using co-precipitation with ferric iron is a proven technology applied in many situations where As must be removed from solution. Hydroxide precipitation of base metals such as copper and zinc has also been known to adsorb As. In all cases, oxidation of As(III) to As(V) can improve treatment efficiency and the production of a stable sludge. Many oxidants can be used with varying costs and degrees of effectiveness (Aubé, 2004).

When treating with ferric iron, it is sometimes necessary to have a two-step process which precipitates most of the As at a slightly acidic pH (4 to 6). Co-precipitation at a low pH is more efficient and can form a more stable precipitate (ferric arsenate). In the second step, any other heavy metals present are precipitated and the remaining arsenic is essentially removed from solution.

When using a clarifier for solid/liquid separation, a sludge recycle can be used to increase treatment efficiency. This can result in significant savings in reagent addition but can also cause the arsenic to be mostly adsorbed as opposed to co-precipitated. Adsorbed arsenic is slightly less stable than when it is co-precipitated as a ferric arsenate. The recycle will also help improve lime efficiency. An excess of iron can be applied with any process to improve sludge stability. The final sludge disposal system can weigh into the decision as to whether a recycle is applied and what ratio of iron to arsenic is used.

LABORATORY TESTS

The first step in the design of a treatment system is to complete some laboratory tests to clearly define the process needs. It is critical that these tests be conducted using a representative sample of water. This section details the raw water sampling, laboratory methodology and test results.

Raw Water

As the mine was entirely flooded, there was a small stream of water continuously overflowing from the mine workings. In the first part of 2007, this water was slightly alkaline (pH 7.6 to 8.5) and contained from 0.2 to 0.4 mg/L of As. The discharge limit for As in Québec is 0.2 mg/L. All other regulated metals (Cu, Fe, Ni, Pb, and Zn) were well within the discharge requirements

As it is common for stratification to occur in mine workings, a ventilation raise was used to obtain water from depth. The deepest sampling point, at approximately 140 m (465 ft) yielded the highest concentration of total As with 0.94 mg/L. Similar to the shallow water, the pH of this water was also alkaline at about pH 8.0. But in contrast with the shallow water, this deep sample contained 2.57 mg/L of Fe. The complete analytical results are given in Table 1. Of note is the comparison between the total dissolved concentrations of Fe and As. Since the pH of the water was alkaline, iron concentrations this high indicate that the iron was in ferrous state. When the sample was pumped up to surface and collected in a 20 L pail, the water was aerated. This caused oxidation of ferrous iron to ferric iron and subsequent precipitation of ferric hydroxides. A photograph of a sample bucket (Figure 3) clearly shows the iron hydroxides settled to the bottom of the bucket; note that the water was clear when pumped up and did not contain a significant amount of suspended solids.

Table 1: Chemistry of Water Sampled at 140 m Depth in Augmitto Mine

Element		- 140 m depth	
		Dissolved	Total
Ag	(ppm)	<0.0001	<0.0001
Al	(ppm)	0.01	0.02
As	(ppm)	0.53	0.94
Ba	(ppm)	0.04	0.04
Ca	(ppm)	N.A	51.7
Cd	(ppm)	<0.0001	<0.0001
Cu	(ppm)	0.002	0.003
Co	(ppm)	0.001	0.002
Cr	(ppm)	0.006	0.002
Fe	(ppm)	0.01	2.57
K	(ppm)	2.0	2.1
Mg	(ppm)	38.2	38.4
Mn	(ppm)	0.033	0.039
Na	(ppm)	15.6	15.2
Ni	(ppm)	0.02	0.03
Pb	(ppm)	0.0001	0.0015
Se	(ppm)	<0.0001	0.000188
Sr	(ppm)	0.59	0.60
SO_4	(ppm)	N.A	43
Zn	(ppm)	0.02	0.11

N.A - not available

Figure 3: Photo of Sample Bucket with Ferric Hydroxide Precipitation

This ferric hydroxide precipitation is important as the treatment of As is completed using iron and this suggests that there is a partial treatment being completed without the addition of any reagents. The difference in As concentration from 0.94 to 0.53 mg/L between the total and dissolved fraction suggests that 44% of the As is treated simply by aeration. Unfortunately, the presence of ferrous iron cannot be depended upon throughout the mine workings. It was not possible to sample directly into the intermediate drifts as the ventilation raise was connected only at the bottom of the existing mine workings and no other access was available.

With a surface As concentration of 0.4 mg/L and a concentration at depth of 0.97 mg/L, it was assumed that the worst-case concentration expected would be approximately 1.0 mg/L As. To be conservative, it was also assumed that the Fe concentrations would be negligible and that treatment would be entirely with added reagents (without the help of in-situ iron).

Methodology

The laboratory tests were completed using 1-L samples of the water collected at depth, as described in Table 1. A total of eleven tests were completed with differing ferric sulphate addition rates, mixing retention times of 15 to 30 minutes, aeration in some tests and peroxide addition in one. The pH was reduced using sulphuric acid in 4 of the tests. The lower pH was applied in some tests as it is known that As co-precipitation is best at pH values of 4 to 6. After neutralisation, the samples were allowed to settle for 24 hours and a sample for analysis was collected from the surface of the 1-L test. The complete test conditions and resulting concentrations of Fe and As are given in Table 2.

Table 2: Laboratory Test Conditions and Results

Test	Fe (mg/L)	pH setpoint	pH actual	Oxidant	H_2SO_4 used (g)	Retention Time (min)	pH Final (24 h)	Dissolved		Total	
								As (ppm)	Fe (ppm)	**As (ppm)**	Fe (ppm)
1	19.8	-	7.46	-	-	-	7.65	0.003	0.01	**0.004**	0.06
2	9.9	-	7.76	-	-	30	8.13	0.015	0.01	**0.052**	0.49
3	4.9	-	8.26	-	-	30	8.50	0.069	0.01	**0.114**	0.41
4	2.5	4.0	4.03	Air	0.28	30	4.23	0.022	0.32	**0.104**	0.72
5	2.5	6.0	6.02	Air	0.27	30	5.78	0.008	0.12	**0.074**	0.45
6	2.5	5.0	4.96	-	0.27	30	5.24	0.010	0.13	**0.060**	0.37
7	2.5	5.0	4.95	10 mg/L Peroxide	0.28	30	5.31	0.004	0.01	**0.074**	0.35
8	2.5	-	8.36	-	-	30	8.36	0.138	0.01	**0.178**	0.19
9	2.5	-	8.60	Air	-	15	8.38	0.153	0.02	**0.187**	0.24
10	4.9	-	8.61	Air	-	15	8.39	0.074	0.01	**0.096**	0.22
11	1.0	-	8.65	Air	-	15	8.39	0.306	0.01	**0.362**	0.27

Laboratory Results

The arsenic discharge limit in Québec is 0.2 mg/L for a monthly average and 0.4 mg/L on a punctual sample. A successful test was deemed to be one with a resulting total As concentration near 0.1 mg/L, or about half the monthly discharge limit. This objective was set in order to ensure that the chosen treatment method would consistently meet the discharge criteria and allow for some room in case of plant upsets. The resulting total As concentrations are displayed in Figure 4. The different symbols represent different iron addition rates, as shown in the legend. All the tests with pH values of more than 7 did not have any pH adjustment. The four tests with lower pH values had been pH-controlled by addition of sulphuric acid.

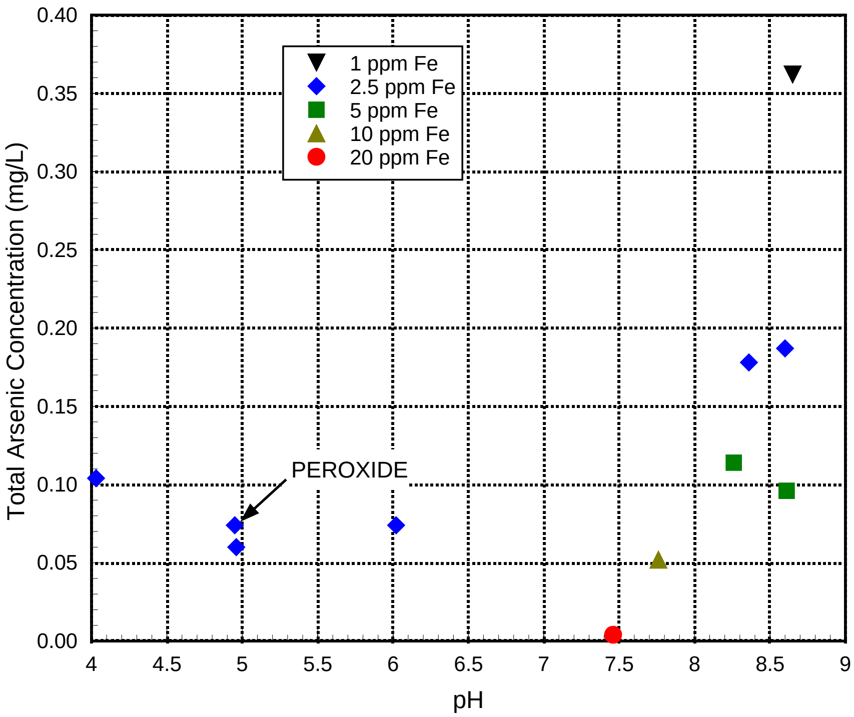

Figure 4: Laboratory Test Results - Arsenic Concentration vs. pH

Figure 4 shows that the higher Fe addition rates remove more As from solution, as expected. An addition rate of 1 ppm (or mg/L) did not meet the requirement of 0.2 mg/L As. A 2.5 ppm Fe addition rate without pH modification resulted in an As concentration just barely below the limit. Two tests completed with an iron addition rate of 5 ppm resulted in As concentrations of about 0.1 mg/L. With 10 or 20 ppm of iron added, the resulting As concentrations were well below the target.

It was possible to meet the objective with an addition rate of 2.5 ppm if the pH was controlled to 5 or 6. Peroxide addition did not have a significant impact on the treatment efficiency. The iron addition rates of 2.5 and 5.0 ppm without acid were conducted both with and without aeration. Aeration did not result in any significant difference.

Recommendations from Laboratory Tests

The results from the lab tests showed that it was possible to treat approximately 1 mg/L of As with 5 ppm iron addition and no pH control. Although treatment was also successful using 2.5 ppm iron with pH control, the incremental capital and maintenance cost of a sulphuric acid system was not considered worthwhile when the simple addition of 2.5 ppm more iron would be sufficient. This is particularly true because by controlling the pH down, it would then need to be increased before discharge. This meant the need for an alkaline system as well, if sulphuric acid were used. Another issue related to the iron concentration: it is more difficult to oxidise ferrous iron to ferric at low pH and it is important to oxidise the ferrous iron for best treatment.

It was recommended to treat the mine effluent with aeration in a reactor sized for a 30-minute retention time. The aeration and retention time were recommended to treat possibly important concentrations of ferrous iron. The collected sample contained 2.6 mg/L of ferrous iron, but the concentration could be higher in different sections of the flooded mine. The discharge limit for Fe is 3 mg/L, but it also serves to help remove the As from solution. By providing a long retention time and aerating the slurry, any iron contained in the mine water would oxidize and help improve the As treatment. Untreated iron in the final effluent would also result in staining in the receiving stream, which is not desirable for aesthetic reasons.

FULL-SCALE SYSTEM DESIGN

Recommendations from the laboratory testing were to construct a reactor with a 30 minute retention time, a ferric sulphate dosing system, and a small blower to aerate for iron oxidation. The solid-liquid separation was to be accomplished in a pond system. Although two ponds were already in place, these were considered small for the expected flowrate when dewatering the mine. A new pond with a volume of 2,500 m^3 was built and labelled as Pond 1. One of the old ponds was significantly enlarged to a volume of 6,500 m^3 and called Pond 2. The final pond, the Polishing Pond (or Pond 3), was not modified – it has an estimated volume of 1,500 m^3. The current configuration of the pond system is shown conceptually in Figure 5.

The final pond was maintained as a Polishing Pond as it may be of use in the future if the raw water chemistry changes during exploitation of the mine. If the As concentrations eventually increase, it may be cost efficient to install a sulphuric acid system and decrease the ferric sulphate consumption. In this case, ponds 1 and 2 would be operated in acidic conditions, probably pH 5 or 6. This means that the effluent pH would need to be increased prior to discharge. This pH increase would be completed in between Pond 2 and the Polishing Pond if it were necessary. This would allow for proper pH equalisation and reduce the chances of forming suspended solids just before the discharge.

For a 30-minute retention time in the reactor, it was built to contain a volume of 62.5 m^3. A 20-ft maritime container was used to lodge a ferric sulphate addition system, the blower, and some electronic components such as for pH monitoring. Due to the low winter temperatures, this container is heated and insulated.

The pond volumes of 2,500 m^3, 6,500 m^3, and 1,500 m^3 (for ponds 1 through 3, respectively) offer a retention time of three days in the first two ponds and 12 hours in the Polishing Pond. The local soil is of low-permeability ($2x10^{-8}$ cm/s) because it contains significant quantities of clay. The pond design called for leaving at least 1 m of clay above the fractured bedrock at the bottom of the ponds. It was therefore initially considered unnecessary to line the ponds as little or no seepage was expected. To comply with the regulation of monitoring the final effluent flowrate, a V-notch was installed at the overflow of Pond 3. The final effluent is monitored for flow and pH daily.

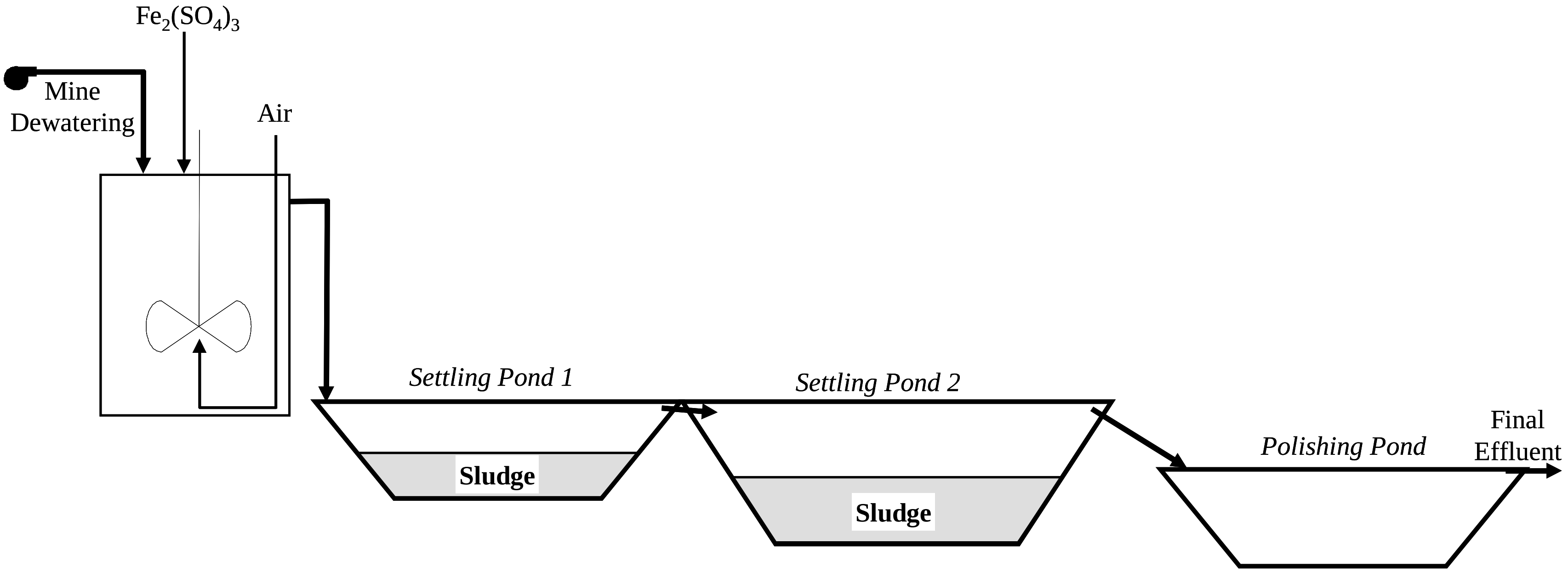

Figure 5: Conceptual Representation of the Augmitto As Treatment System

WATER TREATMENT PLANT OPERATION AND RESULTS

The water treatment plant was commissioned on August 6th 2007 when the partial dewatering started. A total of 381 m of ramp (50 m vertical depth) was dewatered over a 54-day period using a 20 hp Tsurumi submersible pump. The volume of water that was sent to the water treatment plant during the partial dewatering is estimated at 5,800 m^3. The underground infrastructure is being maintained dry by pumping at an estimated rate of 150 m^3/day. The water flow rate variation measured at the final effluent is shown in Figure 6. The average final effluent flow rate during the partial dewatering was 62 m^3/day in August and 310 m^3/day in September. The lack of effluent flow at the start of treatment is due to filling of the sludge ponds (ponds 1 and 2).

After a month of dewatering, it was found that the old portion of the enlarged Pond 2 was leaking. A dye test using a biodegradable FLT green die (certified to ANSI/NSF Standard 60) was performed September 5th 2007 in Pond 2 and confirmed it was leaking. It was then decided to empty Pond 2 into Pond 3 (then the effluent) and proceed with a visual inspection of the pond. A geomembrane was installed in Pond 2 to solve the problem. The water quality monitoring results are presented in Table 3.

Table 3: Treatment Plant and Final Effluent Water Chemistry Monitoring

Sampling site		**Reactor tank intake**		**Pond 2 intake**		**Final effluent**	
2007 Monthly average		**August**	**September**	**August**	**September**	**August**	**September**
pH		7.88	7.8	7.65	7.79	8.14	8.31
T°	**°C**	9.1	9.3	14.4	11.7	19.7	14.0
TSS	**mg/L**	4.4	10.5	3.5	6.42	10.5	6
As	**mg/L**	0.317	0.350	0.033	0.026	0.181	0.183
Cu	**mg/L**	0.007	0.006	0.001	0.002	0.002	0.002
Fe	**mg/L**	0.340	0.726	0.808	1.385	0.168	0.217
Ni	**mg/L**	0.104	0.083	0.078	0.068	0.020	0.057
Pb	**mg/L**	0.002	0.002	0.001	0.001	0.001	0.001
Zn	**mg/L**	0.287	0.024	0.020	0.032	0.002	0.001

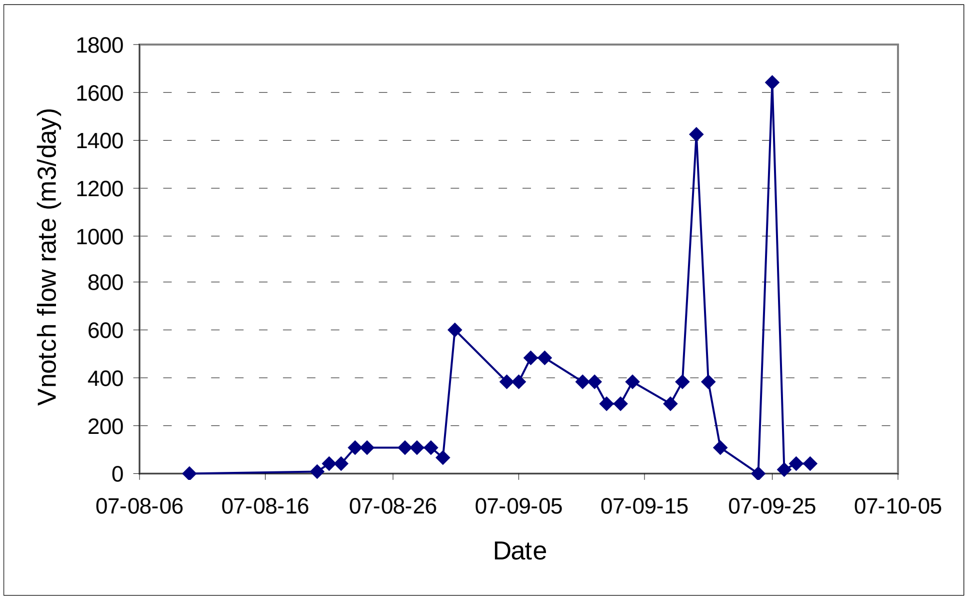

Figure 6: Final Effluent Flow Rate Variations Measured During Partial Dewatering

The pH recorded in the mine water pumped into the reactor tank was neutral to slightly alkaline ranging between 7.66 and 8.15. The pH decreased slightly after the addition of the ferric sulphate in the reactor tank, ranging from 6.02 to 7.77. However, the pH increases after sedimentation of the iron hydroxides in Pond 1 with values ranging between 7.05 and 8.15 in the water fed to Pond 2 (Pond 2 Intake) and between 7.76 and 8.55 in the final effluent, which respects the Québec effluent limits (see Table 3).

The variation of arsenic concentrations is shown in Figure 7. The incoming mine water pumped into the reactor tank had arsenic concentration ranging from 0.294 to 0.417 mg/L. The arsenic concentration decreased drastically after the addition of ferric sulphate and first stage of retention time in Pond 1 (Pond 1 outlet, or Basin 2 Intake), ranging from <0.001 up to 0.036 mg/L. The initial arsenic concentration in the stagnant water of Pond 3 was around 0.2 mg/L before the treatment began. As we can see from Figure 7, the addition of treated water transferring by gravity from Pond 2 to Pond 3 started to dilute the stagnant water in Pond 3. This trend was observed until September 5th at which date the arsenic concentration increased up to 0.25 mg/L. This increase in arsenic concentration seems to coincide with the addition of the green biodegradable dye to identify the leakage in Pond 2. The arsenic concentration started to decrease again when Pond 2 was emptied into Pond 3 to proceed with a visual inspection of the leakage.

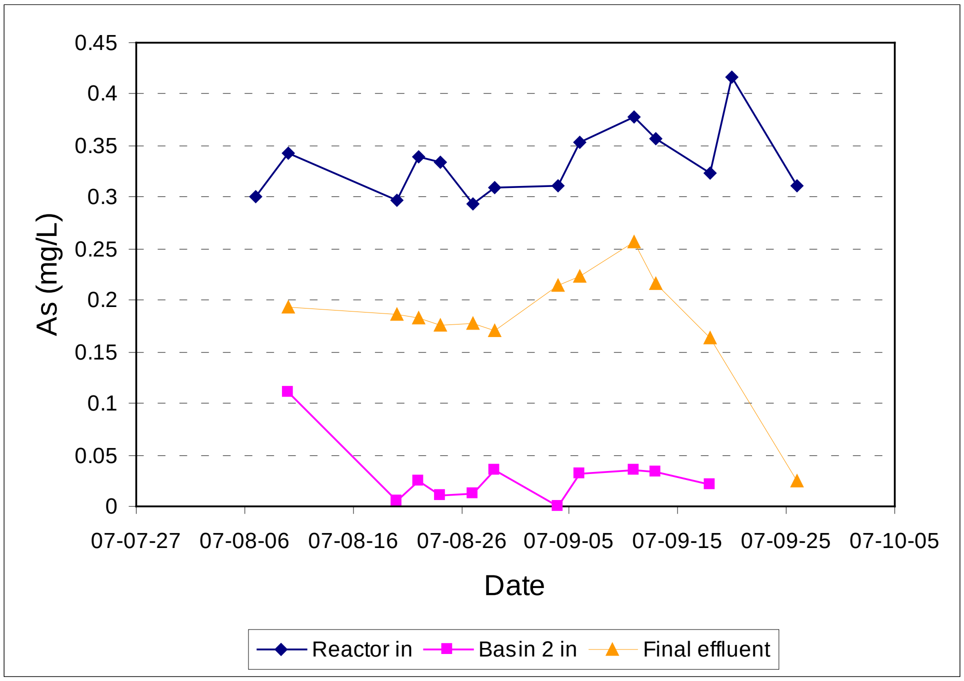

Figure 7: Arsenic Concentrations Variations Measured During Partial Dewatering

Two toxicity tests were conducted during dewatering on the water from Pond 1 and on the final effluent. The toxicity indices were <1 for both the daphnia magna and the rainbow trout tests, thus indicating that the treated water is non toxic. Furthermore, all measured parameters of the final effluent were well within Québec effluent limits.

CONCLUSION

The re-opening of the closed Augmitto Mine requires the dewatering and discharge of water containing arsenic concentrations that exceed local discharge requirements. Sampling of the mine water at depth followed by laboratory tests were needed to design a treatment system that would ensure compliance when de-watering. The treatment process design is to add ferric sulphate for co-precipitation of arsenic and sedimentation of the newly formed solids in a series of ponds with more than three days of retention time. The start-up and initial operation of the treatment system was a success, resulting in an effluent that met all requirements including toxicity.

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